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Publication date:
2014

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Citation (APA):
Espinosa Martinez, N., Laurent, A., Krebs, F. C., & Hauschild, M. Z. (2014). *Will organic photovoltaic technology render benefits in a 30-year horizon?*. Abstract from SETAC Europe 24th Annual Meeting, Basel, Switzerland.

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Will organic photovoltaic technology render benefits in a 30-year horizon?

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1. Introduction

Today, worldwide energy production is largely relying on the use of fossil fuels, which pose significant environmental problems, e.g. their climate change footprint and their increasing scarcity. Solar energy can play an important role in the move towards an increasing utilization of renewable energy sources. By 2060, solar generators are foreseen to make up a major share of the world's energy supply [1].

From that scenario, emerging photovoltaic technologies present an unprecedented opportunity as power supply alternatives. One of the latest generations, organic photovoltaic (OPV) are currently manufactured at the Technical University of Denmark (DTU) [2]. Following their pilot-scale production, installation of OPV modules for power production at a large-scale has been successfully implemented in several forms [3].

Although renewable sources are sometimes flagged as "green energy sources", they may still be associated with important environmental impacts. For addressing their environmental sustainability, life cycle assessment (LCA) can be a useful tool [4]. However, because OPV technologies will only play a key role if they are engineered to create sustainable and efficient power networks in the long term, a dynamic perspective is required in the environmental impact assessment. In this study, we focus on OPV modules used in large-scale applications, e.g. solar parks. We aim to (i) investigate whether these will render benefits within a 30-year horizon, and (ii) identify key parameters within this time horizon that could drive an improvement of the environmental sustainability of the OPV systems and be addressed already today.

2. Materials and methods

We start by assessing the system in a present setting, i.e. with current technology and market features. Manufacturing data are first hand data from a semi industrial-scale production, with a current annual capacity of 0,25 MW_p of flexible OPV modules. We then use forecasting to develop future scenarios to bring a temporal dimension to the assessment.

The product system model has been created mapping elementary flows for all the life cycle stages, from the raw materials extraction over manufacturing processes and use stage to the end of life and final disposal. The energy output from the OPV modules is site-specific due to its dependence on the climatic conditions, i.e. irradiation, which also varies over time (there will be days of high energy output (with sunlight) and days with no output (cloudy)). Therefore, we define our functional unit on an annual basis using single site-specific archetypes of climatic conditions (i.e. daily irradiation integrated over a year). Our functional unit is defined as the average annual supply of 6 PJ_{el} of electricity to the grid from the solar park. As it is an intermittent source, in the days where the solar park cannot provide any electricity, alternative sources are assessed and included in the modelled system.

Through the system evaluation, we identify the following key parameters that we vary in a sensitivity study:

- The module efficiency and lifetime of the OPV cells, which are dependent on the synthesis of polymers with better performance and the development of encapsulants with better barrier properties. Today, the lifetime of OPV modules is one year, which means the production processes will be refined on a yearly basis, e.g. the throughput.
- Different average and marginal energy mixes are addressed in a dynamic dimension, i.e. setting up archetypes of marginal and average energy mixes for different time points, applying forecasting for the performance of these alternative electricity technologies. These are used in all life cycle stages for both energy requirements and crediting.
- The end-of-life scenarios, including increasing recycling efficiencies over time, are also addressed in a prospective approach.

3. Results and discussion

Figure 1 shows the results obtained for the system with current technology features.

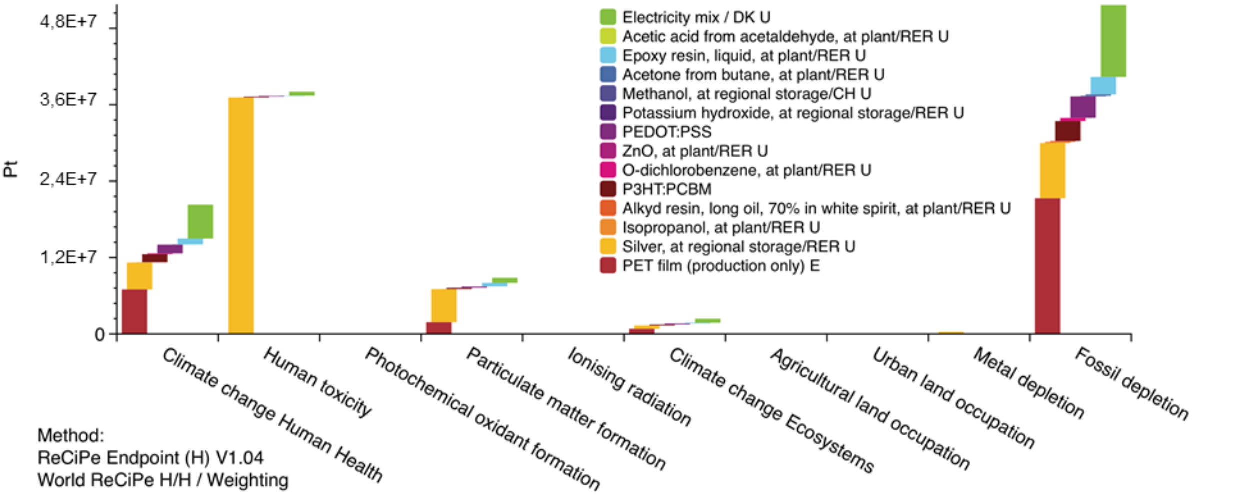

Figure 1. *Impact scores for the cradle-to-gate system per functional unit OPV modules as of today (using ReCiPe 2008 at endpoint).*

Accounting for the dynamic dimension in the results, i.e. assessing the evolutions of the system environmental performances within the coming 30 years, the following points can be brought into focus:

- Some end of life management strategies, as waste incineration with energy recovery, despite being nowadays more sustainable than landfill, may result in less impact savings in a long-term perspective as energy mixes that are used for crediting the incineration increasingly consist of renewable sources [5].
- From the same cause, impact burden-shifting may arise when system expansion is performed during the use stage (for cases when there is no energy output from the solar parks).
- Trade-offs may occur in the future development of the results because these reduced impact savings in the use stage and disposal stage can be compensated by continuously increasing efficiencies of the system, both in the manufacturing stage (production capacity), in the use stage (energy output per unit of OPV modules) and in the disposal stage (e.g. higher recycling rates).
- Shifts may also occur across impact categories, e.g. climate change being significant today while human toxicity dominating in 30 years.

Based on evolutions of these trade-offs over the considered time horizon, we provide recommendations for tackling environmental impacts as early as possible by including environmental performance in a life cycle perspective as a decision criterion in the development and deployment of the OPV technologies.

4. Conclusions

In our study, we provide a comprehensive set of scenarios to bring a dynamic perspective into the LCA of OPV power generation systems. Our results demonstrate that large temporal variations may occur in the LCA results and that these are driven by a few key parameters. They also allow identifying impact trade-offs in a long-term perspective and emphasize the importance of including forecasting analysis in this kind of LCA, where large temporal variations can be expected (e.g. technology developments impacting efficiencies). By doing so, the decision-making process can be based on a long-term perspective and burden shifting that may arise in the future may be anticipated and prevented at the early stages. This is particularly important for energy systems, where national policies are typically set for less than twenty years.

5. References

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